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" " APPARATUS FOR CONTROLLING AN A. C. MOTOR

BACKGROUND OF THE INVENTION

The present invention relates to an apparatus for controlling an a. c. motor and a module using the same.

5 A study paper "Development of full automatic washing machine which is controlled by an inverter" reported in research meeting at Ibaraki Office of Tokyo Branch, The Institute of Electrical Engineers of Japan (IEEJ) (1999) describes "an open loop type vector
10 control scheme" is utilized in an electric motor current sensorless, low resolution position detector.

 Another prior art using a magnetic pole position detector and an electric motor current sensor is disclosed in JP-A-2000-324881 which teaches a
15 control device. In this device an electric current detector directly detects currents flowing through windings of a motor for generating such a voltage instruction that an instructed current is equal to detected currents in a rotary coordinate system.

20 SUMMARY OF THE INVENTION

It is an object of the present invention to provide an apparatus for controlling an a. c. motor which does not cause a shortage of torque in a low speed range without being influenced by variations in

constants of the motor and mounting errors of a Hall effect element and the like.

One of the features of the present invention resides in that motor currents I_d , I_q on the d- and q-
5 axes of a rotary coordinate system are estimated and the voltage output from a power converter are controlled so that the estimated currents I_{dc} , I_{qc} are equal to respective current instruction values I_d^* , I_q^* .

10 Another feature of the present invention resides in that an apparatus for controlling an a. c. electric motor comprises current estimating means which receives detected input d. c. currents from a power converter for converting d. c. power into a. c. power
15 and the rotational phase which is obtained from a signal of detected position of the a. c. motor for outputting estimated current values of the a. c. motor on the d- and q- axes of the rotational coordinate system of the motor, d-axis current controlling means
20 for controlling the d-axis current so that said estimated current value approaches the d-axis current instruction value, and q-axis current controlling means for controlling the q-axis current so that said estimated current value approaches the q-axis current
25 instruction value.

Other objects, features and advantages of the invention will become apparent from the following description of the embodiments of the invention taken

in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows the configuration of a torque control circuit of a permanent magnet synchronization motor of one embodiment of the present invention;

Fig. 2 shows the configuration of a torque control circuit of a permanent magnet synchronization motor of another embodiment of the present invention;

Fig. 3 shows the configuration of a torque control circuit of a permanent magnet synchronization motor of a further embodiment of the present invention;

Fig. 4 shows the configuration of a torque control circuit of a permanent magnet synchronization motor of a further embodiment of the present invention;

Fig. 5 shows a frequency operating unit in the apparatus of Fig. 4;

Fig. 6 shows the configuration of a torque control circuit of a permanent magnet synchronization motor of a further embodiment of the present invention;

Fig. 7 shows the configuration of a torque control circuit of a permanent magnet synchronization motor of a further embodiment of the present invention;

Fig. 8 shows a q-axis inductance operating unit in the apparatus of Fig. 7;

Fig. 9 shows a q-axis current control unit in the apparatus of Fig. 7;

Fig. 10 shows the configuration of the torque

control circuit of the permanent magnet synchronization motor of a further embodiment of the present invention;

Fig. 11 shows an example to which the present invention is applied;

5 Fig. 12 shows an apparatus for controlling the permanent magnet synchronization motor of one embodiment of the present invention;

Fig. 13 shows a d-axis current instruction operating unit 8 in the control apparatus of Fig. 1;

10 Fig. 14 shows a q-axis current instruction operating unit 9 in the control apparatus of Fig. 1;

Fig. 15 shows an apparatus for controlling the permanent magnet synchronization motor of a further embodiment of the present invention;

15 Fig. 16 shows an apparatus for controlling the permanent magnet synchronization motor of a further embodiment of the present invention;

Fig. 17 shows an apparatus for controlling the permanent magnet synchronization motor of a further
20 embodiment of the present invention;

Fig. 18 shows an apparatus for controlling the permanent magnet synchronization motor of a further embodiment of the present invention;

Fig. 19 shows an apparatus for controlling
25 the permanent magnet synchronization motor of a further embodiment of the present invention;

Fig. 20 shows the relationship between the number of rotations and the measured torque when the

" present invention is not used.

Fig. 21 shows the relationship between the number of rotations and the measured torque when the present invention is used.

5 Fig. 22 shows an apparatus for controlling the permanent magnet synchronization motor of a further embodiment of the present invention.

DESCRIPTION OF THE EMBODIMENTS

Now, the present invention will be described
10 by way of embodiments with reference to annexed drawings.

<First Embodiment>

Referring now to Fig. 1, there is shown the configuration of an apparatus for controlling a
15 permanent magnet synchronization electric motor which is an embodiment of the present invention. The apparatus comprises a power converter to which a power from a d. c. power source 21 is input, for outputting voltages which are proportional to three-phase a. c.
20 voltage instruction values V_u^* - V_w^* to an permanent magnet synchronization electric motor 1; a magnetic pole position detector 3 which is capable of detecting the position value θ_i at every electrical angle 60° of the permanent magnet synchronization electric motor 1; a
25 speed calculating unit 4 for calculating the rotational speed ω_1^* of the motor 1 from the detected position value θ_i ; a phase calculating unit 5 for calculating the

rotational phase θ^* of the motor 1 from the detected position value θ_i and the rotational speed ω_1^* ; a current estimating unit 6 for calculating estimated current values I_{dc} , I_{qc} on d-axis (corresponding to magnetic flux axis) and q-axis (corresponding to torque axis) of the rotational coordinate system from input d. c. bus current detected value IDC from the power converter 2; a conversion coefficient which is used for calculating the q-axis current instruction value I_{q^*} from a torque instruction value τ^* ; a voltage vector operating unit 8 for operating voltage reference values V_d^* and V_q^* based upon constants of the motor, current instruction values I_d^* and I_{q^*} , and the rotational speed ω_1^* ; a d-axis current control unit 9 for outputting ΔV_d as a function of the difference between the d-axis current instruction value I_{dc} ; a q-axis current control unit 10 for outputting ΔV_q as a function of the difference between the q-axis current instruction value I_{q^*} and the estimated q-axis current value I_{qc} ; and a coordinate transforming unit 11 for outputting the voltage instruction values $V_u^* - V_w^*$ of three-phase a. c. from the voltage reference values V_d^* , V_q^* , current control outputs ΔV_d , ΔV_q and the rotational phase θ^* as shown in Fig. 1.

The d. c. power source 21 may be primary or secondary battery, or may be power from a capacitor or battery which is charged with a power obtained by rectifying commercial power or a. c. power output from

a generator 23 as is done in a d. c. power source 211. Description of the d. c. power source will be omitted in the embodiments which will be described below since the d. c. power source can be formed similarly to the
5 foregoing.

The torque instruction value τ^* and the d-axis current instruction value I_d^* are determined by a host apparatus. For example, the torque instruction value τ^* is determined depending upon the operation of input
10 devices. The same will be applied to the embodiments which will be described.

Components 1 to 5, 7 and 11 are configured similarly to those for the open loop type vector control used in the low resolution position detector
15 which is disclosed as speed control type in the cited prior art.

Firstly, the basic operation in which the open loop type vector control is applied to the torque control apparatus will be described.

20 In order to control the motor currents I_q , I_d depending upon the q-axis current instruction value I_q^* and the d-axis current instruction value I_d^* determined by the torque instruction value τ^* , the d- and q- axis voltage reference values V_d^* and V_q^* are preliminarily
25 calculated in the voltage vector operating unit 8 in accordance with equation (1) for controlling the output voltages from the converter.

$$\begin{pmatrix} V_d^{**} = R_1^* \cdot I_d^{**} - \omega_1^* \cdot L_q^* \cdot I_q^{**} \\ V_q^{**} = R_1^* \cdot I_q^{**} + \omega_1^* \cdot L_d^* \cdot I_d^{**} + \omega_1^* \cdot K_e^* \end{pmatrix} \quad (1)$$

wherein R_1^* denotes a preset resistance value, L_d^* and L_q^* denote preset values of d- and q- axis inductances, K_e^* denotes a preset value of induced voltage constant, ω_1^* denotes the rotational speed.

5 The position of the magnetic pole at every 60° of the electric angle can be determined by the magnetic pole position detector 3. The detected position value θ_i at this time can be expressed in the present embodiment as follows:

$$\theta_i = 60i + 30 \quad (2)$$

10 wherein $i = 0, 1, 2, 3, 4, 5$.

The averaged rotational speed ω_1^* over a period of at least 60° can be calculated from the detected position value θ_i in the speed calculating unit 4 as follows:

$$\omega_1 = \Delta\theta / \Delta t \quad (3)$$

15 wherein $\Delta\theta$ is $\theta_i - \theta_{(i-1)}$, Δt denotes the time which is taken to detect a position detection signal for a period of 60 degrees. However, due to the presence of mounting errors of the magnetic pole position detector the speed which is averaged over a period of 120° or

more has been practically used.

The phase calculating unit 5 calculates the rotational phase θ^* in accordance with the equation (4) using the detected position value θ_i and the rotational speed ω_1^* for controlling the reference phase of the motor 1.

$$\theta^* = \theta_i + \omega_1^* \cdot \Delta t \quad (4)$$

The basic configuration of the voltage control and the phase control in the open loop type vector control scheme has been described.

When a high torque is required during torque control operation, it is necessary to cause a high current corresponding to the torque to flow. When a high torque is required for an extended period of time, the resistance value R of the windings in the motor increases with the lapse of time due to heating of the motor caused by the current flowing through the motor. Since the preset resistance value R^* which is calculated by the voltage vector operating unit 8 is not equal to the actual resistance value R , the motor 1 can not be supplied with a necessary voltage. As a result, a current which is necessary to generate a requisite torque can not flow, which leads to a shortage of the torque.

Hence, in the present embodiment, the currents I_{dc} and I_{qc} of the d- and q- axes of the

rotational coordinate system are estimated from the d. c. current IDC flowing through the input current bus line of the power converter. The signals ΔV_d and ΔV_q which depend on the current deviation are determined by
5 the d- and q- axis current control units 9 and 10, respectively so that the estimated signals are equal to respective instruction values. The voltage output from the converter is changed by adding the signals ΔV_d and ΔV_q to the outputs of the voltage vector operating unit
10 8. As a result, even if the R^* which is preset by the voltage vector operating unit 8 is not equal to the actual resistance value R , the output voltage can be controlled in such a manner that the currents in the motor are equal to the current instruction values.
15 Thus, high precision torque control can be achieved with a simple configuration without causing a shortage of torque.

Although the voltage reference values V_d^* and V_q^* are calculated using instructed current values I_d^*
20 and I_q^* in the voltage vector operating unit 8, respectively in the present embodiment, similar advantage can be provided by using I_{dc} and I_{qc} which are estimated from the d. c. current IDC.

<Second Embodiment>

25 Referring now to Fig. 2, there is shown another embodiment of the present invention, which is an apparatus for controlling the torque of the permanent magnetic synchronization motor in which the

voltages output from the converter are controlled by controlling only the currents on the d- and q- axis without conducting the operation of the output voltage vector.

5 Components in Fig. 2 which are identical with those in Fig. 1 are represented by reference numerals 1 through 7, 9 through 11, and 21. The difference between the embodiments in Figs. 1 and 2 resides in that the voltage vector operating unit 8 is omitted.

10 Even if the voltage vector operating unit 8 is omitted, the voltages output from the converter can be controlled by the current control units 9 and 10 in such a manner that I_{dc} and I_{qc} are equal to respective instructing values. Thus, high precision torque

15 control can be achieved with a simple configuration without causing a shortage of torque.

<Third Embodiment>

Referring now to Fig. 3, there is shown a further embodiment of the present invention, which is

20 an apparatus for controlling the torque of a permanent magnet synchronization motor of the type in which the instruction values $I_{d^{**}}$ and $I_{q^{**}}$ are obtained from the outputs of the d- and q- axis current instruction calculating units 12, 13. Components in Fig. 3 which

25 are identical with those in Fig. 1 are designated with reference numerals 1 to 7, 11 and 21. A reference numeral 8' denotes a voltage vector operating unit for operating voltage reference values $V_{d^{***}}$ and $V_{q^{***}}$

based upon constants of the motor, signals I_d^{**} and I_q^{**} , respectively and the rotational speed ω_1^* . A reference numeral 12 denotes a d-axis current instruction calculating unit for outputting the I_d^{**} as
5 a function of the deviation between I_d^* and I_{dc} . A reference numeral 13 denotes a q-axis current instruction operating unit for outputting I_q^{**} as a function of the difference between I_q^* and I_{qc} . The output voltages of the converter are controlled by
10 calculating the voltage reference values V_d^{***} and V_q^{***} represented in the equation (5) using the signals I_d^{**} and I_q^{**} , respectively.

$$\begin{pmatrix} V_d^{***} = R_1^* \cdot I_d^{**} - \omega_1^* \cdot L_q^* \cdot I_q^{**} \\ V_q^{***} = R_1^* \cdot I_q^{**} + \omega_1^* \cdot L_d^* \cdot I_d^{**} + \omega_1^* \cdot K_e^* \end{pmatrix} \quad (5)$$

It is apparent that the present embodiment operates similarly to the foregoing embodiments and
15 similar advantages can be provided if considering that i_d^* and I_q^* are equal to I_{dc} and I_{qc} , respectively even in such a scheme.

<Fourth Embodiment>

In the first to third embodiments,
20 interpolation of the phase signals θ^* is conducted by using the rotational speed ω_1^* based upon the position values θ_i which are detected by the magnetic pole position detector 3. It is necessary to conduct a speed averaging processing in the intermediate and high
25 speed range since there are variations in detected

position signals and the like due to the mounting error of the Hall effect element. This calculation lag invites the necessity of high response. Hence, high response can be achieved by controlling the torque control apparatus in a position sensorless manner to eliminate the influences of variations in the detected position signal.

Referring now to Fig. 4, there is shown an exemplary configuration of the fourth embodiment.

Components in Fig. 4 which are identical with those in Fig. 4 are represented with reference numerals 1, 2, 3, 6, 7 to 11, 21. The difference between the embodiments of Figs. 1 and 4 resides in that the fourth embodiment comprises an axial error operating unit 14 which estimates a first phase error $\Delta\theta^*$ which is the difference between the rotational phase instruction θ^{**} and the actual rotor phase θ , based upon the voltage instruction values Vd^{**} and Vq^{**} and the estimated current values I_{dc} and I_{qc} ; a subtractor which determines a second phase error $\Delta\theta^{**}$ which is the difference between the detected position values θ_i ($i = 0, 1, 2, 3, 4, 5$) output from the magnetic pole position detector 3 and the rotational instruction phase θ^{**} ; a combining unit 16 which determines a third phase error $\Delta\theta^{***}$ from the first and second phase errors $\Delta\theta^*$ and $\Delta\theta^{**}$; a frequency calculating unit 17 which calculates a frequency instruction ωl^{**} for the converter using the third phase error $\Delta\theta^{***}$; and a phase

instruction operating unit 18 which determines a rotational phase instruction θ^{**} by integrating the signal ωl^{**} .

The axial error operating unit 14 calculates
5 the first phase error $\Delta\theta^*$ ($= \theta^{**} - \theta$) which is the difference between the actual rotor phase θ and the rotation phase instruction θ^{**} in accordance with the equation (6).

$$\Delta\theta^* = \tan^{-1} \left(\frac{Vd^{**} \cdot R_1^* \cdot Id_c + \omega_1^{**} \cdot Lq^* \cdot Iq_c}{Vq^{**} \cdot R_1^* \cdot Iq_c + \omega_1^{**} \cdot Lq^* \cdot Id_c} \right) \quad (6)$$

This equation is used for the positional
10 error calculation of the position sensorless operating method which is disclosed in JP-A 2001-251889.

The combining unit 16 calculates the third phase error $\Delta\theta^{***}$ by using the above-mentioned first and second phase errors $\Delta\theta^*$ and $\Delta\theta^{**}$, respectively, in
15 accordance with one of three approaches as follows:

A first approach selects a value which is the sum of the first and second phase errors $\Delta\theta^*$ and $\Delta\theta^{**}$ or an average value thereof. A second approach selects larger one of the absolute values of the first and
20 second phase errors $\Delta\theta^*$ and $\Delta\theta^{**}$. A third approach selects less one of the absolute values of the first and second phase errors $\Delta\theta^*$ and $\Delta\theta^{**}$ and is used when the variations in the mounting position of the position detector are larger.

25 Now, the frequency calculating unit 17 will

be described with reference to Fig. 5. In this unit 17, the third axial error $\Delta\theta^{**}$ which is an output of the combining unit 16 is compared with zero. The resultant deviation is multiplied by a proportional gain KPPLL in a proportional operating unit 17A. The deviation is multiplied by an integration gain KIPLL for conducting an integration processing in an integration operating unit 17B. The output of the proportional operating unit 17A is added with the output of the integration operating unit 17B to calculate the frequency instruction ω_1^{**} for the converter.

In the phase instruction operating unit 18, the frequency instruction ω_1^{**} is integrated as shown in equation (7) to calculate the phase instruction θ^{**} . The phase of the output of the power converter 2 is controlled in accordance with θ^{**} via the coordinate converting unit 11.

$$\theta^{**} = \int \omega_1^{**} dt \quad (7)$$

Use of two pieces of information on the position detection signal and the phase error which is estimated from the voltage and current eliminates the necessity of the speed averaging processing to compensate for the variations in the position detection signal, enabling a high response torque control system to be achieved.

Although control and operation is conducted in the axial error operating unit 14 and the d- and q-axis current control units 9 and 10 using I_{dc} and I_{qc} which are estimated from the d. c. current IDC in the fourth embodiment, similar effects can be obtained even using the d- and q- axis current values which are calculated from the detected a. c. current values and the rotational phase instruction of the motor in the motor current detecting unit.

10 <Fifth Embodiment>

In the fourth embodiment, the second axial error $\Delta\theta^{**}$ is determined from the detected position value θ_i ($i = 0, 1, 2, 3, 4, 5$) which are information on actual position output from the magnetic pole position detector 3 and the rotational phase instruction θ^{**} . Since the position can be detected at only 6 phases and is liable to be influenced by the mounting error of the magnetic pole position detector 3 in the fourth embodiment, in order to avoid this problem the rotational phase θ^* which is shown in Figs. 1 to 3 is used, so that the axial error is determined from this rotational phase and the rotational phase instruction θ^{**} in the fifth embodiment.

Now, the exemplary fifth embodiment will be described with reference to Fig. 6. Components which are identical with those in the foregoing embodiments will be designated with the same reference numerals.

The rotational speed ωl^* is calculated from

the detected position value θ_i in accordance with equation (3) in the speed calculating unit 4. The rotational phase θ^* is calculated from the detected position value θ_i and the rotational speed ω_1^* in accordance with equation (4) in the phase calculating unit 5. The difference between the phase instruction θ^{**} and the above-mentioned phase θ^* is determined as the second phase error by using the subtracting unit 15. A reference numeral 16 denotes an adding unit which is used in the above-mentioned first approach in Fig. 6. The adding unit 16 corresponds to the combining unit shown in the fourth embodiment.

Now, operation and effect of the fifth embodiment will be described. A case in which errors between constants which are preset in the voltage vector operating unit 8 and the axial error operating unit 14 and the actual motor constants exist in the control configuration of Fig.6 will be considered.

Firstly, a case in which the second phase error $\Delta\theta^{**}$ is not added to the adding unit 16 which is the combining unit will be considered. The frequency instruction ω_1^{**} is calculated with the calculated first phase error $\Delta\theta^*$ which is calculated in the axial error operating unit 14. The d- and q- axis voltage instructions V_d^{**} , V_q^{**} are calculated as shown in equation (8) in the voltage vector calculating unit 8.

$$\begin{bmatrix} V_d^{**} \\ V_q^{**} \end{bmatrix} = \begin{bmatrix} R_1^* & -\omega_1^{**} \cdot L_q^* \\ \omega_1^{**} \cdot L_d^* & R_1^* \end{bmatrix} \cdot \begin{bmatrix} I_d^* \\ I_q^* \end{bmatrix} + \begin{bmatrix} \Delta V_d \\ \omega_1^{**} \cdot K_e^* + \Delta V_q \end{bmatrix} \quad (8)$$

If the phase error $\Delta\theta$ which is the difference between a signal θ of "control reference axis" and a signal θ^* of "magnetic flux axis of the motor" occurs due to the preset errors of motor constants.

5 Coordinate transformation matrix from the control axis (dc - qc) to the real axis (d - q) is expressed as equation (9).

$$\begin{bmatrix} d \\ q \end{bmatrix} = \begin{bmatrix} \cos \Delta \theta & -\sin \Delta \theta \\ \sin \Delta \theta & \cos \Delta \theta \end{bmatrix} \cdot \begin{bmatrix} d_c \\ q_c \end{bmatrix} \quad (9)$$

If $\Delta\theta$ occurs, the voltages V_d , V_q on the d- and q- axes which are generated on the control side and
10 are applied to the motor are expressed as equation (10) by equations (8) and (9) using preset values of the motor constants.

$$\begin{aligned} \begin{bmatrix} V_d \\ V_q \end{bmatrix} &= \begin{bmatrix} \cos \Delta \theta & -\sin \Delta \theta \\ \sin \Delta \theta & \cos \Delta \theta \end{bmatrix} \cdot \left\{ \begin{bmatrix} R_1^* & -\omega_1^{**} \cdot L_q^* \\ \omega_1^{**} \cdot L_d^* & R_1^* \end{bmatrix} \cdot \begin{bmatrix} I_{dc} \\ I_{qc} \end{bmatrix} + \begin{bmatrix} \Delta V_d \\ \omega_1^{**} \cdot K_e^* + \Delta V_q \end{bmatrix} \right\} \\ &= \begin{bmatrix} \cos \Delta \theta \cdot (R_1^* \cdot I_{dc} - \omega_1^{**} \cdot L_q^* \cdot I_{qc} + \Delta V_d) - \sin \Delta \theta \cdot (R_1^* \cdot I_{qc} + \omega_1^{**} \cdot L_d^* \cdot I_{dc} + \omega_1^{**} \cdot K_e^* + \Delta V_q) \\ \sin \Delta \theta \cdot (R_1^* \cdot I_{dc} - \omega_1^{**} \cdot L_q^* \cdot I_{qc} + \Delta V_d) + \cos \Delta \theta \cdot (R_1^* \cdot I_{qc} + \omega_1^{**} \cdot L_d^* \cdot I_{dc} + \omega_1^{**} \cdot K_e^* + \Delta V_q) \end{bmatrix} \end{aligned} \quad (10)$$

On the other hand, the voltages V_d and V_q on the d- and q- axes which are applied to the motor can
15 be expressed as equation (11) using motor constants.

$$\begin{aligned}
 \begin{bmatrix} V_d \\ V_q \end{bmatrix} &= \begin{bmatrix} R_1 & -\omega_1 \cdot L_q \\ \omega_1 \cdot L_d & R_1 \end{bmatrix} \cdot \begin{bmatrix} I_d \\ I_q \end{bmatrix} + \begin{bmatrix} 0 \\ \omega_1 \cdot K_e \end{bmatrix} \\
 &= \begin{bmatrix} R_1 & -\omega_1 \cdot L_q \\ \omega_1 \cdot L_d & R_1 \end{bmatrix} \cdot \begin{bmatrix} \cos \Delta \theta & -\sin \Delta \theta \\ \sin \Delta \theta & \cos \Delta \theta \end{bmatrix} \cdot \begin{bmatrix} I_{dc} \\ I_{qc} \end{bmatrix} + \begin{bmatrix} 0 \\ \omega_1 \cdot K_e \end{bmatrix} \\
 &= \begin{bmatrix} \cos \Delta \theta \cdot (R_1 \cdot I_{dc} - \omega_1 \cdot L_q \cdot I_{qc}) - \sin \Delta \theta \cdot (R_1 \cdot I_{qc} + \omega_1 \cdot L_q \cdot I_{dc}) \\ \sin \Delta \theta \cdot (R_1 \cdot I_{dc} - \omega_1 \cdot L_d \cdot I_{qc}) + \cos \Delta \theta \cdot (R_1 \cdot I_{qc} + \omega_1 \cdot L_d \cdot I_{dc}) + \omega_1 \cdot K_e \end{bmatrix}
 \end{aligned}
 \tag{11}$$

When current control is conducted by presetting the relationship that the right clause of equation (10) equals the right clause of equation (11),
 5 I_d^* and I_q^* to be zero and a predetermined value, respectively, the values ΔV_d and ΔV_q output from the d- and q- axis current control units 9, 10 can be expressed by equations (12) and (13), respectively.

$$\Delta V_d = \omega_1^{**} \cdot [(L_q^* - L_q) \cdot \sin^2 \Delta \theta \cdot (L_d - L_q)] \cdot I_q^* + \sin \Delta \theta \cdot \omega_1^{**} \cdot K_e \tag{12}$$

$$\begin{aligned}
 \Delta V_q &= (R_1^* - R_1) \cdot I_q^* - \omega_1^{**} \cdot K_e^* + \frac{1}{\cos \Delta \theta} \cdot \omega_1^{**} \cdot K_e \\
 &\quad - \tan \Delta \theta \cdot [\cos^2 \Delta \theta \cdot \omega_1^{**} \cdot (L_d - L_q) \cdot I_q^* + \sin \Delta \theta \cdot \omega_1^{**} \cdot K_e]
 \end{aligned}
 \tag{13}$$

Equation (14) can be obtained by substituting
 10 equation (8) into the first phase error $\Delta \theta^*$ which is calculated in accordance with equation (6) in the axial error operating unit 14.

$$\Delta \theta^* = \tan^{-1} \left(\frac{R_1^* \cdot I_d^* - \omega_1^{**} \cdot L_q^* \cdot I_q^* + \Delta V_d - R_1^* \cdot I_{dc} + \omega_1^{**} \cdot L_q^* \cdot I_{qc}}{R_1^* \cdot I_q^* + \omega_1^{**} \cdot L_d^* \cdot I_d^* + \omega_1^{**} \cdot K_e^* + \Delta V_q - R_1^* \cdot I_{qc} - \omega_1^{**} \cdot L_q^* \cdot I_{dc}} \right)
 \tag{14}$$

Since the relationships $I_q^* = I_{qc}$, $I_d^* = I_{dc}$
 $= 0$ are established by the action of the current
control unit, $\Delta\theta^*$ can be expressed by equation (15).

$$\Delta\theta^* = \tan^{-1} \left(\frac{\Delta V_d}{\omega_1^{**} \cdot K_e^* + \Delta V_q} \right) \quad (15)$$

The first phase error $\Delta\theta^*$ can be expressed by
equation (16) when the outputs of the current control
unit ΔV_d , ΔV_q which are expressed by equations (12) and
(13), respectively are substituted into equation (15).

$$\Delta\theta^* = \tan^{-1} \left(\frac{\omega_1^{**} \cdot \left([(L_q^* - L_q) \cdot \sin^2 \Delta\theta \cdot (L_d - L_q)] \cdot I_q^* + \sin \Delta\theta \cdot K_e \right)}{-(R_1^* - R_1) \cdot I_q^* \cdot \omega_1^{**} \cdot \left(\frac{1}{\cos \Delta\theta} \cdot K_e \cdot \tan \Delta\theta \cdot [\cos^2 \Delta\theta \cdot (L_d - L_q) \cdot I_q^* + \sin \Delta\theta \cdot K_e] \right)} \right) \quad (16)$$

If the second phase error $\Delta\theta^{**}$ is not added to
the adding unit 16, the first phase error $\Delta\theta^*$ which is
expressed by equation (16) is compared with zero. As a
result of PI (proportional and integral) operation with
the deviation signal which is obtained by the
comparison, $\Delta\theta^*$ becomes zero at a constant speed. In
other words, a numerator component of equation (16) has
a relationship of equation (17) at a constant speed.

$$-\sin^2 \Delta\theta \cdot (L_d - L_q) \cdot I_q^* + \sin \Delta\theta \cdot K_e + (L_q^* - L_q) \cdot I_q^* = 0 \quad (17)$$

When the phase error $\Delta\theta$ which occurs at a
constant speed is determined from equation (17),

equation (18) is obtained.

$$\Delta \theta = \sin^{-1} \left(\frac{K_e \sqrt{K_e^2 + 4 \cdot I_q^{*2} \cdot (L_d - L_q) \cdot (L_q^* - L_q)}}{2 \cdot I_q^* \cdot (L_d - L_q)} \right) \quad (18)$$

It is found from equation (18) that the magnitude of the phase error $\Delta \theta$ is related with the preset error of the q- axis inductance ($L_q^* - L_q$).

5 Now, motor torque equation is derived if the phase error $\Delta \theta$ is present.

The torque of the motor on d- and q- axes is expressed by equation (19).

$$\tau_m = \frac{3}{2} \cdot P_m \cdot (K_e \cdot I_q + (L_d - L_q) \cdot I_d \cdot I_q) \quad (19)$$

P_m denotes the number of pairs of poles of the motor.

10 Equation (20) can be obtained when current control is conducted by presetting I_d^* to "zero" in consideration of a coordinate transformation matrix from control axis (dc - qc) to real axis (d - q).

$$\tau_m = \frac{3}{2} \cdot P_m \cdot (\cos \Delta \theta \cdot I_{qc} \cdot [K_e - (L_d - L_q) \cdot \sin \Delta \theta \cdot I_{qc}]) \quad (20)$$

15 It is found from equation (20) that a component " $\cos \Delta \cdot I_{qc} \cdot K_e$ " decreases so that τ_m decreases toward "zero" even if the esstimated q-axis current value I_{qc} is generated according to the instructed value when the phase error $\Delta \theta$ approaches to $\pm \pi/2$ [rad].

In other words, there is a relationship that

the preset error of Lq^* causes the phase error $\Delta\theta$ to decrease the motor torque τ_m .

Hence, if the second phase error $\Delta\theta^{**}$ is added to the adding unit 16 which is a combining unit, it is
5 used as a suggestion signal for modifying the first phase error $\Delta\theta^*$ in the present embodiment shown in Fig .6.

The second phase error $\Delta\theta^{**}$ (equivalent to phase error $\Delta\theta$) which is the difference between the
10 "control reference axis" signal θ^{**} and "motor flux axis" signal θ^* is determined in the subtracting unit 15 as represented by equation(21).

$$\Delta\theta^{**} = \theta^{**} - \theta^* \quad (21)$$

The third phase error $\Delta\theta^{***}$ is calculated as represented in equation (22) by adding the second phase
15 error $\Delta\theta^{**}$ into the first phase error $\Delta\theta^*$ in the adding unit 16.

$$\Delta\theta^{***} = \Delta\theta^* + \Delta\theta^{**} \quad (22)$$

The reference axis for vector control is correctly changed (aligned with the magnetic flux axis of the motor) by calculating the frequency instruction
20 ω_1^{**} of the converter with this third phase error $\Delta\theta^{***}$ and by determining the rotational phase instruction θ^{**} from the signal ω_1^{**} . High precision control of torque

which is proportional to the q-axis current value I_q as represented by equation (19) can be achieved.

<Sixth Embodiment>

The second phase error $\Delta\theta^{**}$ is adopted as the suggestion signal for modifying the reference axis of vector control in the fifth embodiment whereas preset error ΔL_q^* of the q-axis inductance which is used as preset constants of the voltage vector calculating unit 8", axial error calculating unit 14', and q-axis current control unit 10 is calculated using the second phase error $\Delta\theta^{**}$, so that automatic presetting of q-axis inductance is conducted by using the calculated preset error ΔL_q^* .

Referring now to Fig. 7, there is exemplarily shown the configuration of the present embodiment.

Components which are identical with those in Fig. 6 are designated with reference numerals 1 to 7, 9, 11, 15 to 18 and 21. The q-axis inductance operating unit 19 estimates the q-axis inductance present error ΔL_q^* ($= L_q^* - L_q$) from the third phase error $\Delta\theta^{**}$. The voltage vector operating unit 8" calculates voltage reference values V_d^* and V_q^* based upon motor constants, current instruction values I_d^* , I_q^* , frequency instruction ωl^{**} and the q-axis inductance present error ΔL_q^* . The q-axis current control unit 10' modifies the current control gain based upon the q-axis inductance preset value ΔL_q^* . The axial error operating unit 14' calculates the first phase error $\Delta\theta^*$ based upon the

voltage instruction values V_d^{**} , V_q^{**} , estimated current values I_{dc} , I_{qc} and the q-axis inductance preset value ΔL_q^{\wedge} .

Now, operation and effect of the present invention will be described.

As mentioned above, the equation (17) is established at a constant speed in the frequency calculating unit 17. Equation (23) can be obtained by changing equation (17).

$$I_q^* \cdot \left(\cos^2 \Delta \theta \cdot (L_q^* - L_q) - \sin^2 \Delta \theta \cdot (L_d - L_q^*) \right) + \sin \Delta \theta \cdot K_e = 0 \quad (23)$$

ΔL_q ($L_q^* - L_q$) is determined by the following equation (24).

$$\Delta L_q = - \frac{\tan \Delta \theta \cdot K_e}{\cos \Delta \theta \cdot I_q^*} + \tan^2 \Delta \theta \cdot (L_d - L_q^*) \quad (24)$$

ΔL_q^{\wedge} which is the estimated value of ΔL_q can be determined by using L_d^* in lieu of L_d on operation of equation (25).

Assuming $L_d = L_d^*$ does not matter since L_d is less influenced by current saturation.

$$\Delta L_q^{\wedge} = - \frac{\tan \Delta \theta \cdot K_e^*}{\cos \Delta \theta \cdot I_q^*} + \tan^2 \Delta \theta \cdot (L_d^* - L_q^*) \quad (25)$$

A mark * denotes a preset value or instruction value.

Now, an example of the q-axis inductance

operation unit 19 which conducts the operation expressed by equation (25) will be described with reference to Fig. 8. The second phase error $\Delta\theta^{**}$ is input to a function generating unit 19A which
5 calculates $\tan(\Delta\theta^{**})$ and a function generating unit 19B which calculates $\cos(\Delta\theta^{**})$ and the outputs of the function generating units 19A and 19B are then input to a dividing unit 19C where the dividing operation is conducted. The output of the dividing unit 19C is
10 multiplied by an induced electromotive voltage constant K_e^* . Its product is input to the dividing unit 19D together with the estimated q-axis current value. I_{qc} is used in lieu of I_q^* which is represented in equation (26).

15 The output $\tan(\Delta\theta^{**})$ of the function generating unit 19A is input to the multiplier 19E where it is squared. The square of the output of the multiplier 19A is multiplied by the difference ($L_d^* - L_q^*$) between the d-axis inductance preset value L_d^* and
20 d-axis inductance preset value L_d^* . Its product is input to the subtracting unit 19F together with the output of the dividing unit 19D. The output of the subtracting unit 19F becomes the q-axis inductance present error ΔL_q^{\wedge} .

25 If the motor has a relationship $L_d \doteq L_q^*$ (salient pole is small), equation (25) can be simplified into equation (26).

$$\Delta Lq^{\wedge} = \frac{\tan \Delta \theta \cdot K\theta^*}{\cos \Delta \theta \cdot lq^*} \quad (26)$$

Now, a method of reflecting the q-axis inductance preset error ΔLq^{\wedge} which has been thus determined on the control system will be described.

Operation of equation (27) is conducted using
5 a signal ΔLq^{\wedge} in the voltage vector operating unit 8".

$$\begin{bmatrix} Vd^* \\ Vq^* \end{bmatrix} = \begin{bmatrix} R1^* & -\omega_1^{**} \cdot (Lq^* - \Delta Lq^{\wedge}) \\ \omega_1^{**} \cdot Ld^* & R1^* \end{bmatrix} \cdot \begin{bmatrix} Id^* \\ lq^* \end{bmatrix} + \begin{bmatrix} 0 \\ \omega_1^{**} \cdot K\theta^* \end{bmatrix} \quad (27)$$

Similarly, operation of the equation (28) is also conducted using the q-axis inductance preset error ΔLq^{\wedge} in the axial error operating unit 14'.

$$\Delta \theta^* = \tan^{-1} \left(\frac{Vd^{**} - R^* \cdot Id_c + \omega_1^{**} \cdot (Lq^* - \Delta Lq^{\wedge}) \cdot lq_c}{Vq^{**} - R^* \cdot lq_c - \omega_1^{**} \cdot (Lq^* - \Delta Lq^{\wedge}) \cdot Id_c} \right) \quad (28)$$

By modifying the preset q-axis inductances
10 which are represented by equations (27) and (28), the modification of Lq^* makes the phase error $\Delta \theta$ zero so that the motor torque τ_m which is the same as instructed value can be generated. High precision position sensorless control can be achieved.

15 The proportional gain of the q-axis current control unit 10' can also be changed by using the signal ΔLq^{\wedge} . The configuration of the q-axis current control unit 10' is exemplarily illustrated in Fig. 9.

The differential signal between the signal

I_q^* and the signal I_{qc} is input to the proportional operating unit 10'A together with the q-axis inductance preset error ΔL_q^* . The proportional operating unit 10'A calculates the proportional gain $K_{P_{ACR}}$ in accordance with equation (29) using the q-axis inductance preset error ΔL_q^* . The calculated gain $K_{P_{ACR}}$ is multiplied by the differential signal ΔI_q to provide an output signal.

$$\begin{aligned} K_{P_{ACR}} &= \omega_c \cdot (L_q^* - \Delta L_q^*) \\ &= \omega_c \cdot L_q \end{aligned} \quad (29)$$

wherein ω_c denotes the closed loop response frequency of the current control system (rad/s).

The integration operation unit 10'B conducts an integration by multiplying the signal ΔI_q by the integration gain $K_{P_{ACR}}$. The output of the integration operation unit 10'B is added with the output of the proportional operating unit 10'A for providing a signal ΔV_q which is used for changing the output voltage of the converter.

High torque response as is preset can be obtained by calculating the proportional gain $K_{P_{ACR}}$ based upon the q-axis inductance preset error ΔL_q^* even if there is a preset error in the q-axis inductance.

Control gain of the q-axis current control unit is changed based upon the q-axis inductance preset error ΔL_q^* in the present embodiment. Similar effect can be obtained even by applying the present invention

to the changing of control gain of the q-axis current instruction operating unit.

<Seventh Embodiment>

In the former embodiment, the third phase
5 error $\Delta\theta^{**}$ is obtained by adding the second phase error $\Delta\theta^{**}$ with the first phase error $\Delta\theta^*$. Alternatively, the q-axis inductance preset error ΔLq^* can be calculated from the second phase error $\Delta\theta^{**}$ even by making the third phase error $\Delta\theta^{***}$ equal to the first phase error
10 $\Delta\theta^*$ without adding the second phase error $\Delta\theta^{**}$. It is obvious that an effect which is similar to that of the former embodiment can be obtained.

The configuration of the seventh embodiment is exemplarily illustrated in Fig. 10. The present
15 embodiment is substantially identical with that shown in Fig. 7 except that the first phase error $\Delta\theta$ which is an output of the axial error operating unit 14 is directly input to the frequency calculating unit 17.

Further description will be omitted since
20 operation and effect of the present embodiment is identical with that of the former embodiment.

<Eighth Embodiment>

An example in which the present invention is applied to a module will be described with reference to
25 Fig. 11. The present embodiment is an example of the first embodiment. A speed calculating unit 4, phase calculating unit 5, current estimating unit 6, constant 7, voltage vector operating unit 8, d-axis current

control unit 9, q-axis current control unit 10, and coordinate transforming unit 11 are formed of a one-chip microcomputer. The one-chip microcomputer and power converter are accommodated in one module formed
5 on one and same board. A term "module" used herein means a standardized component which may be formed of separable hardware/software elements. The module is preferably formed on one and same board for ease of manufacturing, but is not limited thereto. The module
10 may be formed on a plurality of circuit boards which are disposed in one and same housing.

The module may take similar form in the other embodiments.

<Ninth Embodiment>

15 Fig. 12 shows the configuration of control system of a permanent magnet synchronization motor which is one of a. c. motors of one embodiment of the present invention.

A reference numeral 100 denotes a permanent
20 magnet synchronization motor; 2100 denotes a d. c. power source; 2000 denotes outputs from the output of a d. c. power source; 2100 denotes voltages which are proportional to three-phase a. c. voltage instruction values V_u^* , V_v^* , V_w^* ; 3000 denotes a current detector
25 which is capable of detecting three-phase currents I_u , I_v , I_w ; 4000 denotes a magnetic pole position detector which is capable of detecting the position detection value θ_i at every 60° of electrical angle of the motor;

5000 denotes a phase calculating unit for calculating the rotational phase instruction θ_c^* of the motor from the position detection value θ_i and the frequency instruction value ωl^* ; 7000 denotes a power converting unit for outputting d- and q- axis current detection values I_{dc} , I_{qc} from the detected values I_{uc} , I_{vc} , I_{wc} of the three-phase alternating currents I_u , I_v , I_w and the rotational phase instruction θ_c^* ; 8000 denotes a d-axis current instruction operating unit for outputting a second d-axis current instruction value I_{d}^{**} depending upon the difference between the first d-axis current instruction value I_d^* and d-axis current detection value I_{dc} ; 9000 denotes a q-axis current instruction operating unit for outputting a second q-axis current instruction value I_{q}^{**} depending upon the difference between the first q-axis current instruction value I_q^* and the q-axis current detection value I_{qc} ; 1000 denotes a voltage vector operating unit for operating voltage instruction values V_{d}^{**} , V_{q}^{**} based upon motor constants, second current instruction values I_{d}^{**} , I_{q}^{**} and frequency instruction value ωl^* ; and 1100 denotes a coordinate transforming unit for outputting three-phase voltage instruction values V_u^* , V_v^* , V_w^* from the voltage instruction values V_{d}^{**} , V_{q}^{**} and the rotational phase instruction θ_c^* .

Firstly, the basic operation of the d-axis current instruction operating unit 800 and the q-axis current instruction operating unit 900 which is one of

features of the present invention will be described.

The d-axis and q-axis current detection values I_{dc} , I_{qc} are calculated from the three-phase a. c. values I_{uc} , I_{vc} , I_{wc} which are detected by the
5 current detector 300 and the rotational phase instruction θ_c^* in the coordinate transforming unit 700. The second d-axis and q-axis current instruction values $I_{d^{**}}$, $I_{q^{**}}$ are calculated in the d- and q- axis current instruction calculating units 800, 900, respectively,
10 so that the current detection values I_{dc} , I_{qc} are equal to the first d-axis and q-axis current instruction values I_{d^*} , I_{q^*} which are provided from host apparatus.

The voltage vector operating unit 1000 calculates voltage instruction values $V_{d^{**}}$, $V_{q^{**}}$ by
15 using calculated current instruction values $I_{d^{**}}$, $I_{q^{**}}$ and motor constants as represented by equation (100) for controlling the output voltage from the converter.

$$\begin{pmatrix} V_{d^*} = R_1^* \cdot I_{d^*} - \omega_1^* \cdot L_q^* \cdot I_{q^*} \\ V_{q^*} = R_1^* \cdot I_{q^*} - \omega_1^* \cdot L_d^* \cdot I_{d^*} + \omega_1^* \cdot K_e^* \end{pmatrix} \quad (100)$$

In equation (100), R_1^* denotes preset value of the resistance of the motor; L_d^* denotes preset
20 value of the d-axis inductance; K_e^* denotes preset value of the induced voltage constant; ω_1^* denotes frequency instruction value; the magnetic pole position detector 400 detects the position of the magnetic poles at every 60° of electrical angle. The position
25 detection value θ_i at this time is represented in the

present embodiment by the equation as follows:

$$\theta_i = 60i + 30 \quad (200)$$

In equation 200, $I = 0, 1, 2, 3, 4, 5$. The frequency calculating unit 500 calculates the frequency instruction value ω_1^* which is an averaged rotational speed for a period of at least 60° from the position detected value θ_i in accordance with equation (300).

$$\omega_1^* = \frac{\Delta \theta}{\Delta t} \quad (300)$$

In equation (300), $\Delta \theta$ denotes $\theta_i - \theta_{(i-1)}$; Δt is a period of time which is taken to detect a position detection signal in an interval of 60° . The phase operating unit 600 calculates the rotational phase instruction θ_c^* by using the position detected value θ_i and frequency instruction value ω_1 in accordance with equation (400) for controlling the reference phase of the motor 1.

$$\theta^* = \theta_i + \omega_1^* \cdot \Delta t \quad (400)$$

The basic operation of the voltage and phase control in the vector control apparatus of the permanent magnet synchronization motor of the present invention has been described.

Now, the configuration of the d-axis current

instruction operating unit 800 and the q-axis current instruction operating unit 900 which is one of the features of the present invention will be described. The configuration of the d-axis current instruction
5 operating unit 800 is illustrated in Fig. 13. The proportional operating unit 800A multiplies the difference between the first current instruction value I_d^* which is given from the host apparatus and the current detection value I_{dc} by the proportional gain
10 K_{pd} . The output from the proportional operating unit 800A is added with the output from the integration operating unit 800B which conducts an integration operation by multiplying the difference by an integration gain K_{id} for outputting the second d-axis
15 current instruction I_d^{**} .

$$I_d^{**} = (I_d^* - I_{dc}) \cdot \left(K_{pd} + \frac{K_{id}}{s} \right) \quad (500)$$

The configuration of the q-axis current instruction operating unit 900 is illustrated in Fig.
20 14. The proportional operating unit 900A multiplies the difference between the first current instruction value I_q^* which is given from the host apparatus and the current detection value I_{qc} by a proportional gain
25 K_{pq} . The output of the proportional operating unit 900A is added with the output from the integration operating unit 900B which conducts an integration operation by multiplying the difference by an

intégation gain K_{iq} for outputting the second q-axis current instruction $I_{q^{**}}$.

$$I_{q^{**}} = (I_{q^*} - I_{qc}) \cdot \left(K_{pq} + \frac{K_{iq}}{s} \right) \quad (600)$$

Herein a proportion plus integration operation is conducted in the d-axis current instruction operating unit 800 and q-axis current operating unit 900. Only proportion or integration operation can provide similar effect.

Now, an effect and operation of the present invention will be described by way of the present embodiment.

A case in which the first d- and q- axis current instruction values I_{d^*} , I_{q^*} are input to the voltage vector operating unit 1000 in the control system of Fig. 12 will be considered (the second current instruction values $I_{d^{**}}$, $I_{q^{**}}$ are not used for the arithmetic operation). The vector operating unit 1000 calculates the voltage instruction values V_{d^*} , V_{q^*} in accordance with equation (700).

$$\begin{pmatrix} V_{d^*} = R_1^* \cdot I_{d^*} - \omega_1^* \cdot L_q^* \cdot I_{q^*} \\ V_{q^*} = R_1^* \cdot I_{q^*} + \omega_1^* \cdot L_d^* \cdot I_{d^*} + \omega_1^* \cdot K_e^* \end{pmatrix} \quad (700)$$

If a higher torque is required when the torque control is carried out in accordance with vector operation of equation (700), it is necessary to provide a high current consistent with the torque. If higher

torque is continuously required for an extended period of time, the resistance R of the winding in the motor increases with lapse of time due to heat generation by a current flowing through the motor. Since the preset
5 resistance value R^* which is calculated in the voltage vector operating unit 1000 becomes unequal to the actual resistance value R , the voltage which is required by the motor 1 can not be supplied. As a result, a current which is required for generating
10 necessary torque does not flow particularly in a low speed range, so that a shortage of torque occurs.

Fig. 20 shows the relation between measured motor torque and the number of rotation when the vector operation is conducted in accordance with equation
15 (700). In the drawing, a broken line denotes the instructed torque value and a solid line denotes measured motor torque value. It is found that a torque as is instructed is not generated in the range of high torque and low speed (range A) which is encircled by a
20 broken line. Second current instruction values I_d^{**} , I_q^{**} are calculated in the current instruction operating units 800, 900 so that the d- and q- axis current detection values I_{dc} , I_{qc} are equal to respective instruction values which are provided by the
25 host apparatus. The voltages output from the converter are calculated in accordance with equation (700).

As a result, even if R^* which is preset in the voltage vector operating unit 1000 is not equal to

actual resistance value R , the output voltages can be controlled so that the motor currents equal to current instruction values. High precision torque control can be achieved in a whole range of speeds.

5 Fig. 21 shows a result of measurement in the present embodiment. Broken lines in Figs. 20 and 21 denote torque instruction values. Solid lines denote actual torque values which are measured for respective torque instruction values. Comparison of Fig. 20 with
10 Fig. 21 shows the actual torque values in the present embodiment of Fig. 21 follow the instruction values at a higher precision than that in Fig. 20. In particular, it is found that the actual torque values follow the instructed torque value in a low speed range
15 of about 25 [Nm] at a precision which is at most 8 [Nm] higher in Fig. 21 than in Fig. 20. In other words, it is found that a torque as is instructed is generated in a low speed and high torque range in Fig. 21 showing the experiment result of the present embodiment.

20 It is possible to cause the actual torque to follow the instructed torque values at a high precision over a whole speed range. Higher torque output can be achieved particularly in a low speed range.

<Tenth Embodiment>

25 Fig. 15 shows a tenth embodiment of the present invention. In tenth embodiment, a control system for a permanent magnet synchronization motor is provided in which the second current instruction values

I_d^{***} , I_q^{***} are obtained from sums of the first d- and q- axis current values I_d^* , I_q^* and the output values I_d^{**} , I_q^{**} of the current instruction operating units 800, 900, respectively.

5 In Fig. 15, components which is represented as 100 to 1100, 2100 are identical with those in Fig. 12. A reference numeral 1200 denotes an adding unit for adding the first d-axis current instruction value I_d^* to the output value I_d^{**} of the d-axis current
10 instruction operating unit 800; 1300 denotes an adding unit for adding the first q-axis current instruction value I_q^* and the output value I_q^{**} of the q-axis current instruction operating unit 900. The voltage instruction values V_d^{***} , V_q^{***} which are represented
15 by equation (800) are calculated using the current instruction values I_d^{***} , I_q^{***} which are calculated by this method for controlling the output voltage of the converter.

$$\begin{pmatrix} V_d^{***} = R_l^* \cdot I_d^{***} - \omega_l^* \cdot L_q^* \cdot I_q^{***} \\ V_q^{***} = R_l^* \cdot I_q^{***} + \omega_l^* \cdot L_d^* \cdot I_d^{***} + \omega_l^* \cdot K_e^* \end{pmatrix} \quad (800)$$

 In this system, the current instruction
20 values which are proportional to a torque to be generated are principally supplied from I_d^* , I_q^* .

 Even if the motor constants which are preset in the vector operating unit 1000 do not match the actual values of the motor, high precision torque
25 control can be achieved over the entire range of speeds

since the current instruction values are calculated by the current instruction operating units 800, 900 so that the motor currents match the current instruction values (or compensate for excessive or insufficient
5 currents). Considering that I_d^* and I_q^* are equal to I_{dc} and I_{dq} , respectively, it is apparent that the present invention provides similar effects and operation of the previous embodiments.

If the period of the sampling operation is
10 long, the control gain can not be increased, so that high response can not be achieved. However, it is possible to increase the response by conducting a feedforward control in the present embodiment.

<Eleventh Embodiment>

15 Fig. 16 shows an eleventh embodiment of a control system for the permanent magnet synchronization motor in which the second current instruction values I_d^{***} , I_q^{***} are obtained from a signal of time lag or advance of first order of the first d- and q- axis
20 current instruction values I_d^* , I_q^* and the sums of the signals of time lag of first order of the current instruction values I_d^* , I_q^* and the current instruction values I_d^{**} , I_q^{**} which are calculated from the detected current values I_{dc} , I_{qc} .

25 Components which are represented as 100 to 1100, 2100 in Fig. 16 are identical with those 100 to 1100, 2100 in Fig. 12. A reference numerals 1200 denote an adding unit for adding the output value I_d^{**}

of the d-axis current instruction operating unit 800 to
the d-axis first current instruction value I_d^* ; 1300
denotes an adding unit for adding the output value I_q^{**}
of the q-axis current instruction operating unit 900 to
5 the q-axis first current instruction value; 1400
denotes a filter of time lag of first order having a
time lag constant T_{d1} ; 1500 denotes a filter of time
lag and advance of first order having a gain of a time
lag constant T_{d1} and a time advance constant T_{d2} ; 1600
10 denotes a filter of time lag of first order having a
lag time constant T_{q1} ; and 1700 denotes a filter of
time lag and advance of first order having a lag time
constant T_{q1} and an advance time constant T_{q2} . The
voltage instruction values V_d^{***} , V_q^{***} which are
15 represented as equation (900) are calculated using the
current instruction values I_d^{***} , I_q^{***} which are
calculated by this method, for controlling the voltages
output from the converter.

$$\begin{pmatrix} V_d^{***} = R_1 \cdot I_d^{***} - \omega_1 \cdot L_q \cdot I_q^{***} \\ V_q^{***} = R_1 \cdot I_q^{***} + \omega_1 \cdot L_d \cdot I_d^{***} + \omega_1 \cdot K_e \end{pmatrix} \quad (900)$$

The proportional gains (K_{pd} , K_{pq}) and
20 integral gains (K_{id} , K_{iq}) of the d- and q- axis current
instruction operating units 800, 900 are preset as is
shown in equation (1000).

$$\left(\begin{array}{l} K_{pd} = \frac{L_d^*}{R^*} \cdot \omega_{cd} \\ K_{id} = \omega_{cd} \\ K_{pq} = \frac{L_q^*}{R^*} \cdot \omega_{cq} \\ K_{iq} = \omega_{cq} \end{array} \right) \quad (1000)$$

wherein ω_{cd} , ω_{cq} denote d- and q- axis control response angular frequency [rad/s] and L_d , L_q denote inductances of the motor; and R denotes the resistance of the motor. T_{1d} , T_{2d} , T_{1q} , T_{2q} are expressed as execution
5 (1100) in operating units 1400 to 1700.

$$\left(\begin{array}{l} T_{1d} = \frac{1}{\omega_{cd}} \\ T_{2d} = \frac{L_d^*}{R^*} \\ T_{1q} = \frac{1}{\omega_{cq}} \\ T_{2q} = \frac{L_q^*}{R^*} \end{array} \right) \quad (1100)$$

Since the current control response from the current instruction values I_d^* , I_q^* to the current detection values I_{dc} , I_{qc} can be defined with a time lag of first order as expressed by equation (1200), it
10 is possible to construct an overshootless torque control system.

$$\left(\begin{array}{l} \frac{Idc}{Id^*} = \frac{1}{1 + \frac{1}{\omega_{cd}} \cdot s} \\ \frac{Iqc}{Iq^*} = \frac{1}{1 + \frac{1}{\omega_{cq}} \cdot s} \end{array} \right) \quad (1200)$$

By considering the fact that Id^* and Iq^* are equal to Idc and Iqc , respectively in even such a system, it is apparent that the present embodiment provides effects and operation similar to that of the previous embodiment and that an overshootless torque control system can be constructed.

<Twelfth Embodiment>

Three-phase a. c. currents I_v to I_w are detected in the expensive current detector 300 in the embodiments 9 to 11. However, current detection can be conducted without using any current detector in the present embodiment. The twelfth embodiment is shown in Fig. 17. Components which are represented as 100, 200, 400 to 1100 and 2100 in Fig. 17 are identical with those represented as 100, 200, 400 to 1100 and 2100 in Fig. 12, respectively. A reference numeral 1700 denotes a current estimating unit for estimating three-phase a. c. currents I_d , I_v , I_w flowing through the synchronization moor based upon a d. c. current IDC flowing through the input bus line (d. c. shunt resistor) of the power converter.

The d- and q- axis current detection values I_{dc} , I_{qc} are calculated using the estimated current values I_u^* , I_v^* , I_w^* in coordinate transforming unit 700. Since I_d^* and I_q^* are equal to I_{dc} and I_{qc} ,
5 respectively, in even such a system, effect and operation similar to the previous embodiment can be provided.

Since I_{dc} , I_{qc} are determined by means of a d. c. shunt resistor which is preliminarily
10 incorporated for preventing an overcurrent in lieu of a current detector, control can be carried out with less current detector.

<Thirteenth Embodiment>

Thirteenth embodiment is an embodiment in
15 which the control system of Fig. 15 is applied to a control system which detects a current in an economical manner. The thirteenth embodiment is shown in Fig. 18. Components which are represented as 100, 200, 400 to 1100 and 2100 in Fig. 18 are identical with components
20 represented as 100, 200, 400 to 1100 and 2100 in Fig. 15, respectively. A reference numeral 1700 denotes a current estimating unit for estimating three-phase a. c. currents I_u , I_v , I_w flowing through the synchronization motor based upon a d. c. current I_{DC} flowing
25 through the input bus line (d. c. shunt resistor) of the power converter.

The d- and q- axis current detection values I_{dc} , I_{qc} are calculated using the estimated current

values I_u^* , I_v^* , I_w^* in the coordinate transforming unit 700. Since I_d^* and I_q^* are equal to I_{dc} and I_{qc} , respectively in even such a system, effect and operation similar to the previous embodiments can be provided. Since I_{dc} , I_{qc} are determined by means of a d. c. shunt resistor which is preliminarily incorporated for preventing an overcurrent in lieu of a current detector, control can be carried out with less current detector.

10 <Fourteenth Embodiment>

Fourteenth embodiment is an embodiment in which the control system of Fig. 16 is applied to a control system which detects a current in an economical manner. The fourteenth embodiment is shown in Fig. 19. Components which are represented as 100, 200, 400 to 1100 and 2100 in Fig. 19 are identical with components represented as 100, 200, 400 to 1100 and 2100 in Fig. 16, respectively. A reference numeral 1700 denotes a current estimating unit for estimating three-phase a. c. currents I_u , I_v , I_w flowing through the synchronization motor based upon a d. c. current I_{DC} flowing through the input bus line (d. c. shunt resistor) of the power converter. The d- and q- axis current detection values I_{dc} , I_{qc} are calculated using the estimated current values I_u^* , I_v^* , I_w^* in the coordinate transforming unit 700. Since I_d^* and I_q^* are equal to I_{dc} and I_{qc} , respectively in even such a system, effect and operation similar to the previous

embodiments can be provided.

Since I_{dc} , I_{qc} are determined by means of a d. c. shunt resistor which is preliminarily incorporated for preventing an overcurrent in lieu of a current detector, control can be carried out with less current detector.

<Fifteenth Embodiment>

Fig. 22 shows a fifteenth embodiment of a control system of a permanent magnet synchronization motor of the present invention in which a voltage vector operation is conducted by using the first and second current instruction values $I_{d^{**}}$ and $I_{q^{**}}$ on the d- and q- axis sides, respectively. Components which are represented as 100, 700, 800 to 1100 and 2100 in Fig. 22 are similar to those represented as 100 to 700, 800 to 1100 and 2100 in Fig. 12, respectively.

Since I_{q^*} is equal to I_{qc} in this method if the d-axis current instruction value is zero ($I_{d^*} = 0$), effect and operation similar to that of the previous embodiments can be obtained.

In accordance with the present invention, there is provided a control system for an a. c. motor which does not cause shortage of torque in the low speed range without being influenced by variations in motor constants and mounting error of a Hall-effect element.

It should be further understood by those skilled in the art that although the foregoing

description has been made on embodiments of the invention, the invention is not limited thereto and various changes and modifications may be made without departing from the spirit of the invention and the
5 scope of the appended claims.